Cascades Volcanoes - Processes and Hazards

A Five Day Field Trip - Mount Baker to Mount St. Helens
September 25 - 30, 1998

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Welcome to the 1998 field trip to Cascades Volcanoes (Fig. 1). This road guide will provide an overview of selected geological features along our five-day route. We will focus mainly on mounts Baker (Fig. 2), Rainier, and St. Helens, but will also see deposits from Glacier Peak volcano. Along the way we will pass by the deposits of several large landslides that are probably evidence of large earthquakes. To avoid repetition, supplemental information about the volcanic history, processes, and hazards of the Cascade Range will be provided. We will have a special focus on Mount Rainier, which in 1992 was selected as one of the 15 Decade Volcanoes worldwide.

Acknowledgments

This road guide is, in large part, a compilation of the work and contributions of many active researchers such as Kevin Scott, Wes Hildreth, Donald Easterbrook, Derek Booth, Matt Brunengo, Jim Beget, Tom Sisson, Jim Vallance and many others. Joe Hull contributed information regarding the location of deposits and buried forests noted by Beget of buried forests in the White Chuck River basin. Alycia Ladd and Leslie Pringle assisted during field reconnaissance. A previous, expanded version of this guide was published for the 1994 Geological Society of America's meeting in Seattle (Pringle 1994a).

September 25, 1998

This road log starts at the United States-Canadian border. This short leg on September 25 takes us to Sedro Woolley on the Skagit River via State Route (SR) 9. The road travels along the west side of American Sumas Mountain through the Sumas Valley, an extension of the Fraser Lowland, then juts eastward up the Nooksack River valley to Deming, and then south to Sedro Woolley in the Skagit River drainage. Bedrock in this area is the faulted (Cretaceous age) metamorphic and sedimentary sequence of the San Juan-North Cascades System (Brown et al., 1987). Most of the area was covered by the Vashon lobe of the Continental Ice sheet during the most recent major glaciation and has a complicated glacial history, much of which has been documented or interpreted by Easterbrook (1963, 1969, 1976, 1994), Armstrong and Clague (1977), Armstrong (1981), and more recently by Dethier et al. (1995), Kovenan (1996), and Dragovich et al. (1997a,b,c,d). Lahars (volcanic debris flows) from Mount Baker have traveled at least as far as the SR 542 bridge at Cedarville on the Nooksack River. An unusually high concentration of large rockslides and debris avalanches in this area suggests it has an extensive history of earthquakes (Engebretson et al., 1995, 1996; Pringle et al., 1998). Dinner will be at Domaine de Chaberton winery with views east to Mount Baker.

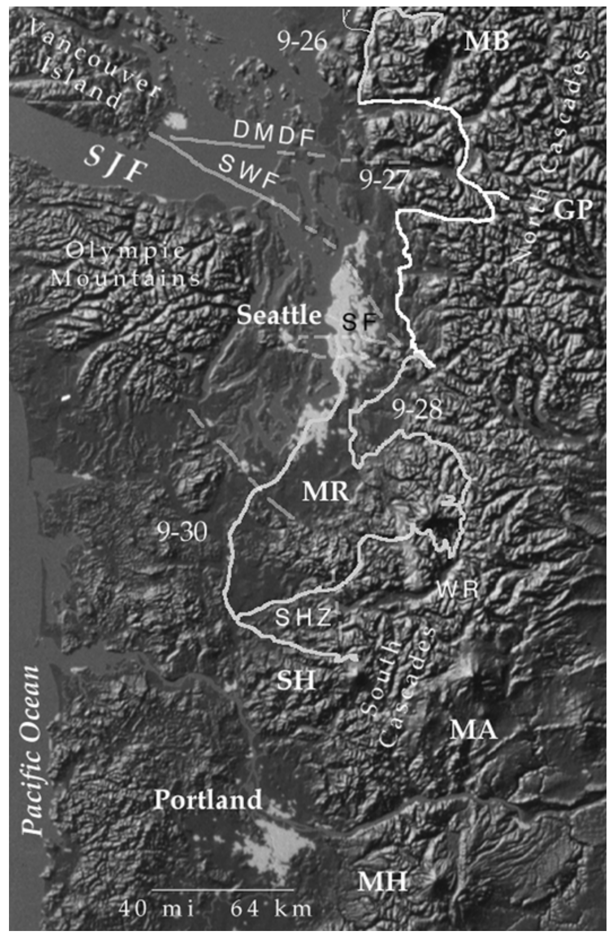

FIGURE 1. Shaded relief image of Washington State generated from GIS data shows overall terrain visited by this trip and approximate locations of field trip legs for each day. The following symbols are for geographic features: MB, Mount Baker; GP, Glacier Peak; MR, Mount Rainier, SH, Mount St. Helens, MA, Mount Adams, MH, Mount Hood, and SJF, Strait of Juan de Fuca. Selected inferred shallow-crustal faults are shown as well DDF, Devils Mountain-Darrington, SWF, South Whidbey, SF, Seattle, and SHZ, St. Helens, and WR, West Rainier fault zones.

0.0 Depart Sumas and follow State Route (SR) 9 as it winds it way south and east through the Sumas Valley and west of Sumas Mountain.

FIGURE 2. View to the north of Mount Baker volcano, August 21, 1997 by Lee Gerhardt. Steam plume rises from Sheman Crater (lower crater), source of increased fumarolic activity that began in 1975. There are no signs to suggest that magma movement has had any effect on this change in heat flow. Recent ice-radar measurements by Carolyn Driedger (USGS) and Nadine Nereson (UW) indicate that Summit Crater is filled with as much as 80 m of snow and ice. Mount Baker has had at least four eruptions in the past 14 000 years.

1.6 Vedder Mountain is visible to the east. This northeast-trending landform is probably the surface expression of an active fault zone. Several rockslides have been noted on its north flank, but none have been dated. The Sumas Moraine records a glacial readvance that occurred sometime after late Wisconsin ice had receded north of here (Easterbrook, 1969; Armstrong and Clague, 1977; Armstrong, 1981). Johnson Creek, which flows from the south into the Fraser River, flows along the path of an ancestral channel of the Nooksack River which flowed north into the Fraser prior to about 6000 years ago (Cameron, 1989). Although the Nooksack has drained into Bellingham Bay to the south, it has flooded the Sumas Valley during historic times.

4.5 Intersection of SR 9 and SR 546; go left on SR 9.

5.0 Milepost (MP) 93.

7.2 Town of Nooksack.

7.7 Go left at the intersection of SR 9 and SR 544. Optional trip for view of the Smith Creek Landslide—continue ahead, make a left on South Pass Road for 0.9 mi. The landslide is visible at about 1:00.

9.2 Right on Godwin Road.

10.0 Smith Creek.

11.8 Right onto Hopewell Rd.

12.6 Gravel pit.

13.6 SR 9, take a left. During heavy precipitation of 1996, a slope movement on Sumas Mountain triggered an explosion as it broke a major gas pipeline. This was the second such incident in Washington State caused by that episode of precipitation.

14.6 Mount Baker Highway at Cedarville, take another left and continue east on SR 9. Mount Baker is ahead in the distance (Fig. 3). Deposits of a kame delta were exposed on the north side of the valley in 1996 about 1 mi (1.6 km) northeast of Cedarville. Radiocarbon ages indicate that the delta formed sometime after about 11 600 yr B.P. (Dragovich et al., 1997a). A volcanic ash deposit (10-20 cm) sits on slightly weathered? drift at the base of the prodelta muds. This ash deposit locally contains grains and lapilli of black, microvesicular scoria that may have been erupted from Mount Baker. Ripple-drift cross laminations (delta front) and coarse grained crossbeds (delta top) indicated currents flowing to the east, perhaps from ice that had

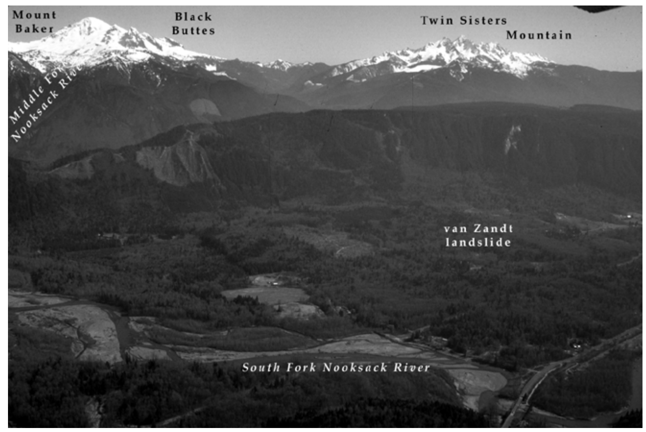

FIGURE 3. Telephoto view to the east up the Nooksack River valley from Smith Road, about 1.6 mi (2.6 km) southwest of Cedarville. Mount Baker volcano and Black Buttes, an erosional remnant of a pre-Mount Baker cone, are shown in the left distance. Twin Sisters, composed of dunite, is in the right distance.

readvanced south past the entrance to the Nooksack River valley at Sumas Mountain. This readvance could have formed a temporary lake in the Nooksack River valley, which is suggested by similarity in elevations of the top of the delta (just over 300 ft elev.) and the elevation of the divide between the South Fork Nooksack River and Samish Rivers (320 ft; southern lip of the impounded basin). A 3-m thick, fine-grained deposit containing dropstones caps the delta deposit, possibly correlative with the Everson glacial marine drift described by Easterbrook (1976).

19.2 SR 9 south to Sedro Woolley. Within a half mile the road rises up gently over a landslide deposit from Van Zandt Dyke. The Van Zandt rockslide-debris avalanche originated to the east and is composed of Eocene Chuckanut Sandstone.

21.4 Van Zandt.

26.6 Acme.

30.5 Park Road to Lake Whatcom.

34.6 Samish River.

40.2 Northwest Regional Office of the Washington Department of Natural Resources (WA DNR).

41.0 SR 9 intersection with SR 20.

September 26, 1998

We journey north along SR 9 from the Skagit River watershed to that of the Nooksack River, and, at the junction of SR 542, we turn right and head north along the North Fork Nooksack River valley. Our journey takes us over lahar terraces created by the extensive clay-rich Middle Fork lahar from Mount Baker, past large landslides (many probably generated by ancient earthquakes), and across fault zones, some of which have been active, either historically, or in recent geological history. At the town of Glacier we begin a steeper ascent up the North Fork Nooksack River valley and onto the lavas and fragmental deposits of Mount Baker volcano.

Mount Baker Volcano

Hyde and Crandell (1978) provided an earlier overview of the postglacial volcanic history of Mount Baker volcano, however, little was known about the chronology of eruptive activity because of a dearth of radiocarbon dates. Kevin Scott of the United States Geological Survey (USGS), who is investigating the fragmental deposits at the volcano, has begun to accumulate radiocarbon and stratigraphic data that will allow for a revised chronology of eruptive and flowage events. Scott's investigations coincide with those of Wes Hildreth, also USGS, who is studying the lava flows and pre-Holocene fragmental deposits of Mount Baker.

FIGURE 4. View to the east of subfossil trees and tree molds in the Middle Fork Nooksack River lahar of Hyde and Crandell (1978). Photo by Ken Cameron.

Mount Baker has had major tephra eruptions about 12 000 yr B.P.? (or later) and at about 5500 yr B.P. (Kevin Scott, written comm., 1998) as well as sporadic smaller emissions. Lahars have flowed down nearly all drainages with the largest, the clay-rich Middle Fork Nooksack lahar, reaching at least as far as the Sumas Valley in the Fraser Lowland. Some eruptive activity has been reported in historic times as noted in Harris (1988).

0.0 SR 9 intersection with SR 20.
0.8 Northwest Regional Office of the WA DNR.
6.4 Samish River.
10.5 Park Road to Lake Whatcom.
14.4 Acme.
19.6 Van Zandt.
21.8 SR 9 intersection with SR 542.
22.7 "Carol's Coffee Cup. The flat terrace in this area is a clay-rich (cohesive) lahar deposit from Mount Baker that Hyde and Crandell (1978) called the Middle Fork lahar (Fig. 4). Kovenan (1996) has recently dated this lahar at about 5500 yr B.P. This age is similar to a radiocarbon age reported by Kevin Scott of the USGS on a major pumice layer from Mount Baker (Kevin Scott, written comm., 1998).
24.0 Mosquito Lake Road.
26.1 Large Boulders at MP 19 are part of the Racehorse Creek rockslide debris avalanche. Pringle et al. (1998) have provisionally dated this debris avalanche at about 3700 yr B.P., or younger.
30.0 Intersection of SR 542 and SR 547 at Kendall.
30.8 Till on the north.
31.1 MP 24.
32.9 Maple Falls and Silver Lake Road.
33.2 Maple Creek.
33.4 Boulders of Eocene Chuckanut Formation are visible along the edges of road in this area, evidently part of a large rockslide from the mountain to the south of the Nooksack River.
36.5 Mount Baker pull off. At 10 750 ft, Mount Baker is the northernmost active volcano in Washington State. The American Indian name for Mount Baker is Komo Kulshan, which means steep. The mountain was sighted by Joseph Baker of Vancouver's expedition on April 30, 1792. Eocene Chuckanut Formation outcrops on the north side of the highway.
37.6 Mounds containing Chuckanut Formation sandstone?
37.9 Nooksack River.
39.4 Slide Mountain rockslide (Chuckanut Formation) visible at 2:00.
39.5 Cross Cornell Creek. Note the snags in the river, remnants of trees buried by aggradation.
40.2 Town of Glacier.
40.4 Glacier Creek. Thompson et al. (1992) found

evidence for at least two lahars from Mount Baker in Glacier Creek. Mounds containing Chuckanut Sandstone are exposed locally along the road for the next several miles. These mounds are part of a rockslide-debris avalanche deposit described by Cary et al. (1992a,b) and Carpenter (1993). The age of that landslide was recently reinterpreted by Pringle et al. (1998) at about 2320 yr B.P. That date is intriguingly similar to the revised date (2410 ±50 yr B.P.) for a major explosive eruption at Meager Mountain volcano, located 90 mi (150 km) north of Vancouver (Clague et al., 1995).

FIGURE 5. Distorted lava columns of Mount Baker andesite. The lava was probably deposited against glacial ice, causing the unusual column orientation.

FIGURE 6. Mount Baker from Table Mountain trail. View is to the southwest. Geologist is Alycia Ladd.

40.6 Forest Service station. Restrooms and drinking water.
41.0 Mount Baker Rim development.
41.5 Church Mountain is straight ahead. The exposed rock and poorly developed soil near the top of the peak denote the source area of the Church Mountain rockslide-debris avalanche.
46.8 House-size blocks on the left are from the Church Mountain rockslide-debris avalanche.
48.2 Outcrop of the Nooksack Formation; pullout. The Mount Baker Quadrangle (1:100 000-scale) has been mapped by Tabor et al. (1994).
50.1 Colluvium (avalanche?) visible to the north. Old-growth forest in this area.
52.8 Pullout to the right with view of Mount Shuksan.
53.5 Nooksack Bridge and Hannegan Road.
55.0 Spectacular view of Mount Baker dead ahead.
56.1 Bagley Creek bridge.
56.5 Diamicton having <1 m of weathering. Could be latest Wisconsinan alpine till.
58.7 Columnar-jointed lava flow at 3:00.
59.4 Grand view. Several pullouts are available, but there are no guard rails.
59.7 Diamicton, probable glacial till at hairpin turn to the left.
60.0 Distorted lava columns of mount Baker andesite (Fig. 5). This lava probably was erupted adjacent to glacial ice, as noted in a recent paper by Lescinsky and Sisson (1997).
64.3 Alpine Lakes parking area. We will hike up on the Table Mountain Trail for a spectacular view of Mount Baker volcano (Fig. 6). A visit to Mount Baker winery will end the day.

September 27, 1998

Today we will depart Sedro Woolley and drive east up the Skagit River valley, first visiting the lower Baker dam. We will then cross the Skagit River and head south up the Sauk River, which drains Glacier Peak volcano. We travel past pumiceous terraces that are relicts of Glacier Peak's explosive past (Fig. 7, 8) and of the many lahars that have passed this way.

Glacier Peak Volcano

Glacier Peak is not even recognized as a volcano by many residents of the northwest (Mastin and Waitt, 1995). Early studies identified thick deposits from explosive eruptions that had blocked the Stillaguamish River and forced the Sauk River to flow into the Skagit (Vance, 1957; Tabor and Crowder, 1969). However, studies of it's late glacial and Holocene eruptive and flowage deposits by Beget has proved otherwise (Beget, 1982, 1983). Beget found explosive Holocene eruptions during the intervals 5500-5100, 2800-1800, and 1800-1000 yr B.P. (and probably at other times). He also noted lahars that flowed as much as 100 km from the volcano and probable eruptive activity within the past 200 years. Waitt et al. (1995) have recently revised the volcanic hazard assessment for Glacier Peak.

0.0 SR 9 intersection with US 20.
4.0 Coal Creek alluvial fan, MP 70.
16.0 Baker Lake Road.
16.4 About MP 84; Chevron at Birdsview.
21.3 MP 87.5; Fish Creek. North Cascade Inn.
22.0 Stefanie's at Concrete.
22.6 Andesitic(?) boulders on the left.
22.9 Bridge over the Baker River.
23.1 Left at Everett Road and follow the signs toward Lake Shannon.

24.2 Turn left at the visitor center. We will stop at the center briefly then go up the road a short distance and look at the dam.

26.8 Near MP 92 note flat terrace on south side of highway.

32.7 Junction SR 153 and SR 20.

34.7 Cascade River Road.

34.8 Terrace about 12 m on the east (lahar?).

35.2 Illabot Creek Road. Take this to get to the Slide Lake landslide dam, dated by Pringle et al. (1998) at younger than about 400 yr B.P.

39.3 MP 61.

40.1 Lahar terrace(?) south of White Chuck Creek at about 2:00 (SW) in left bank of the Sauk.

40.9 More terraces.

42.2 Road ascends a lahar(?) terrace.

43.7 Suiattle River Road on the east.

43.9 Sauk River bridge; valley widens.

50.5 Darrington Ranger Station on the west.

52.1 Darrington. We will rezero the odometer here.

0.0 Go south from Darrington on the Mountain Loop Highway.

2.1 Cut through terrace.

2.7 Enter national forest land.

3.1 Clear Creek and campground.

3.4 Greenstone (Shuksan); pullout on east side.

3.6 Old Sauk River Trail (east side)

8.7 Confluence of Sauk and White Chuck rivers.

8.8 Forest Road 22. Laharic deposits are visible upstream of the bridge in a 15 m and nested 4 m terrace. From the pull off (to the right) slightly past the bridge, one can hike upstream to see older deposits exposed on the right (north or "river right") valley wall. The deposits exposed in low terraces at the bridge are some of the youngest flowage deposits from the volcano, but most are older than about 300 yr based on the ages of trees growing on the deposits (Beget, 1982).

8.9 White Chuck River Road.

Optional Side Trip to see buried forests and volcanic deposits in the White Chuck River valley.

Optional side trip here goes about 6 miles farther upstream to see stacked buried forests, lahar deposits, and a thick diamicton that may be a debris avalanche deposit. For buses, the limiting factor for this site is time, because the only turnaround is at the Kennedy Creek Campground and involves a 22 mi round trip up this dusty, mostly one-lane road. The following mileages for the side trip are measured from the main forest road (Old Sauk River Trail).

1.7 Big trees on the left here can provide some minimum age for the surface.

4.0 Cross the Straight Creek Fault (SCF) about here. The SCF is a major terrane boundary that separates the Northwest Cascades System (a stack of late Paleozoic strata and early Cretaceous blueschist) from the gneiss, migmatites, and

FIGURE 7. Telephoto view of Glacier Peak from Pugh Mountain. View is to the east; photo by Matt Brunengo.

FIGURE 8. Jeff Jones examines a stack of Glacier Peak lahar deposits and buried forests along the White Chuck River. Arrows show locations of several buried trees and roots. These units dip to the north-northeast because of slumping in the underlying clay-rich hummocky diamicton. This hummocky deposit apparently began as a debris avalanche from Glacier Peak sometime before 5500 yr B.P. (Beget, 1982) and blocked the valley, as indicated by the presence of common lake silts.

plutons of the "crystalline core".

4.3 Granite talus and boulders is part of a rockslide from Pugh Mountain.

5.7 FR 2700—Mendocs Mountain Road.

6.0 A brownish diamicton visible to the left contains yellowish-stained rock fragments and large, broken chunks (megaclasts) of silt (lake beds?). This deposit has a hummocky surface and probably began as a debris avalanche from Mount Baker. Beget (1982) notes that it underlies the Kennedy-Dusty Creek assemblage of deposits (5100-5500 yr B.P.).

6.6 Park at a small pull off on the right, and walk 50 m up the road to the southeast. A view from the top edge of the terrace here reveals at least 3 lahar deposits lying atop the silt-bearing diamicton noted at mile 6 above. Given its great thickness (10 m+?), the mixture of volcanic debris and lacustrine silts megaclasts, and hummocky surface, this unit is probably the deposit of a debris avalanche from Glacier Peak. The layers of lahars sitting atop the hummocky surface, which include at least 2 or 3 buried forests, are tilted backward to the north-northeast and indicate that a large block of the debris avalanche material has undergone a slump-like rotation.

End of optional field trip

Reset odometer to zero at intersection of White Chuck Road and Mountain Loop Highway.

0.0 Mountain Loop Highway and FR 23. Head south on the Mountain Loop Highway.

0.2 Outcrop of White Chuck assemblage of lahars, erupted from Glacier Peak between about 12 500 and 11 250 yr B.P. (Beget, 1982).

0.6 Overlook and restroom site.

0.7 MP 7.

7.3 Bedal Creek Campground.

7.5 Sauk River.

8.5 Debris flow (boulder levees?).

10.3 Large boulders are evidence of a rockslide.

10.8 Diamictons visible at more than 1800 ft elev. Could these fine-grained deposits be from Glacier Peak?

12.8 A scarp visible high to ESE could be the source of the large boulders noted at mile 10.3.

14.1 Barlow Pass, elev. 2351 ft.

18.5 Ice Caves Trailhead. A casualty and major injury resulted this year from partial collapse of one of the ice caves. Marble Peak is visible to the south.

25.7 Sinkhole?

26.3 Youth on Age Nature Trail.

28.0 Boardman Campground.

29.8 White Creek Campground.

31.8 Hemple Creek picnic area.

44.8 Granite Falls.

44.8 South out of Granite Falls on Granite Ave.

46.8 Pilchuk River.

47.5 Left at Y on Robe-Menzell Lake Road.

50.7 Menzell Lake Rd.

53.0 Lake Roesiger.

54.0 Lake Roesiger Park; restrooms

55.6 Left on Woods Creek Rd.

63.0 Bear right on Woods Creek Road.

64.1 Left on Woods Creek road; then enter the broad valley of the Skykomish River.

66.1 SR 2: right to SR 203.

66.3 Left on SR 203.

67.2 Skykomish River.

69.3 Cadman High Rock Quarry.

71.6 MP 19; bedrock exposed.

72.6 King County Border.

75.5 Glacial deposits visible on the left (east) just before downtown Duvall; MP 15.

77.4 Seattle Water Dept. Tolt River.

82.0 Stillwater.

84.6 Carnation.

85.5 Tolt River; mountains at 10:00.

90.8 Fall City.
90.9 SR 202. At the stop sign, go left to North Bend.
92.3 Mount Si dead ahead.
94.7 Snoqualmie Falls overlook. If we have time, we will stop here and view the falls. After leaving the falls area, continue southeast on SR 202.
95.2 Snoqualmie River.
96.0 Town of Snoqualmie.
96.7 SR 202 again at Snoqualmie; Jims Auto Repair marks spot to turn right from lodge and head up to winery.
97.4 Turn onto North Bend Way.
98.5 Veer left under freeway and follow signs to Snoqualmie Winery.
100.3 Snoqualmie Winery. Scenic vistas, glacial history and discussion of Seattle fault.

September 28, 1998

0.0 Road log begins at I Exit 31.
3.5 Brick wall "holding" landslide from Rattlesnake Mountain.
5.0 Exit to I-90 intersection with SR 18 at Echo Glen Rd.
5.0 End of off ramp to SR 18 at intersection of I-90.
26.0 Landslide complex just north of Green River.
26.3 Green River.
29.3 C St. SW.
30 Jct of SR 167 go southbound to continue on field trip; go northbound for optional field trip to buried forest at Auburn.

Optional field trip to Auburn Buried Forest.

Go north to the 15th St. North exit; go left at 15th St. and drive west a short distance to West Valley Road. Go south on West Valley Road to Main St., then turn left (east) and go less than one-half mile and turn left (north) on Clay St. About 1/3 mile north on Clay is a wetland owned by the Emerald Downs Racetrack. When the wetland was excavated in 1995, a buried forest was discovered. The forest had been killed by a pumiceous lahar runout from Mount Rainier (Fig. 9, 10). The runout is a massive, pumiceous sand deposit that contains abundant wood fragments. A radiocarbon age on outer wood from a tree stump in the deposit was 1100 yr B.P.; another buried forest was found in Kent, 11 km north of here, and correlative sand deposits have been found as far north as the Port of Seattle in the lower Duwamish valley, 27 north of here (Pringle et al., 1997). The top of the sand deposit is about 54 ft elev. (Gary Jones, personal comm., 1998). This deposit is evidently correlative with the lahars of Deadman Flat described by Vallance in Scott et al. (1995) and is the largest lahar to flow down the White River valley since the Osceola Mudflow about 5000 yr B.P.

The Duwamish valley was carved during and after the Vashon glaciation. A study of well logs (Dragovich and

FIGURE 9. Photo showing a tree stump buried by a 0.7 m pumiceous sand and gravel deposit from Mount Rainier. The deposit is a distal runout from the Deadman Flat lahar described by Vallance in Scott et al. (1995). That lahar was the largest flow to inundate the White River valley since the Osceola Mudflow. View is the east-southeast.

FIGURE 10. Close up of the pumiceous sand and gravel deposit exposed at Auburn. Trenching tool is about 0.45 m long. Inset shows delicate, angular glass shard (2 mm) from deposit. Arrow shows bottom of sand deposit.

others, 1994) confirms that, at present sea level, an arm of Puget Sound would have extended up the Puyallup Valley about as far as Sumner south to about 6 km north of the Sumner before deposition of the Osceola Mudflow about 5,000 yr B.P. Tens of meters of debris flow deposits from Mount Rainier, as well as fluvial deposits, now underlie the valley floor. Similarly, in the Puyallup River valley an arm of the sound would have extended southeast to near the west side of the City of Puyallup. Increases in slope of the surface of the Osceola deposit and a dramatic decrease in thickness (from as much as 18 m slightly upstream of the delta top to <4 m on the delta front) mark the passage of that mudflow over the delta. Apparently there has been more than 400 km^2 of alluviation in the Puyallup and Duwamish valleys since the Osceola Mudflow.

End of optional field trip. Retrace route and head south on SR 167: Take the SR 410 east exit (to Yakima).

0.0 The field trip log starts at the intersection of State Route (SR) 516 and the valley freeway (SR 167) at Kent in the Duwamish valley. Go south on SR 167.

13.1 Exit right onto SR 410. Head east on SR 410 for about 2 mi and exit onto SR 162. Go south (right) toward Orting. We cross the Puyallup River about 0.6 mi south of SR 410. The farthest downstream outcrops of the Electron Mudflow (channel fill deposit) and the Osceola Mudflow are here. The top of the Osceola deposit is about 7 m below the bridge. Many eye-witness accounts of liquefaction were documented in this area during the M 7.1 1949 earthquake (Chleborad and Schuster, 1990). Black sands composing the sand boils had originated in lahar runout deposits from Mount Rainier (Palmer and Pringle, 1991; Pringle and Palmer, 1992).

Lower(?) Pleistocene laharic deposits of the Alderton and Puyallup Formations of Crandell et al. (1958) are exposed in the valley walls near Alderton. The two units are separated by the Stuck Drift of Crandell et al. (1958); all are reversely magnetized (Easterbrook, 1994) and thus lie within the Matuyama Reversed Polarity Chron (0.8 to 2.4 Ma).

21.2 Stop. Orting buried forest. At the town of Orting (Fig. 11), turn right into the Whitehawk subdivision. This area was inundated by the Electron Mudflow about 530 yr B.P. Recent excavations on the west side of the highway have exposed remnants of a

FIGURE 11. Aerial-oblique view to the southeast showing the town of Orting, about 50 km downstream of Mount Rainier. The town is underlain by a stack of lahars from the volcano. Steve Brantley, USGS, photo.

FIGURE 12. Large Douglas-fir stump discovered by excavators at the town of Orting is part of a buried forest that underlies the town. The forest was killed by the Electron Mudflow, a clay-rich lahar from Mount Rainier (Crandell, 1963, 1971). Radiocarbon dating of the innermost 4 rings of this tree (355 rings from bark) shows the tree died around AD 1400 or shortly before. Inset shows that the Electron Mudflow occurred in the springtime, about late March or early April, based on the beginnings of a new annual growth ring (arrow) just beneath the bark.

buried old growth forest (mostly Douglas fir) that was preserved within as much as 6 m of mudflow (Fig. 12). Some of the excavated snags are lying on the surface, and several in-place snags stick up in the storm water retention pond north of the subdivision entrance. The 5 m (16 ft) chunk of andesitic volcanic breccia nearby was excavated here as well.

Development pressures have been intense in this area of the Puyallup Valley, which was designated as an area of moderate volcanic hazards by Crandell (1963). 1990 legislation, the Washington Growth Management Act (Title 36.70A RCW), mandates that all jurisdictions will (among other things) designate “critical areas” including geologically hazardous areas. The Washington Department of Community, Trade and Economic Development developed “minimum guidelines” for defining volcanic hazard areas (Chapter 365-190 WAC, Section (4fi)). Local geology professor Al Eggers (University of Puget Sound) served on a citizens advisory board to the Pierce County Planning Department and was influential in the appraisal of volcanic (and other) hazards that have been considered in designing the county’s comprehensive land use plan.

Continue south on SR 162 through the town of Orting.

24.7 At the Electron turnoff continue east on SR 162 up the valley of Prairie Creek, interpreted by Crandell to be the pre-Osceola valley of the White River.

27.0 New Carbon River bridge replaces the old trestle bridge that was partly undermined by flood erosion in 1990.

33.9 End of SR 162 at the intersection of SR 165 to Buckley and the Carbon River entrance to Mount Rainier National Park. This is the closest access to the park from Seattle. Turn north toward Buckley.

The highway ascends from the floodplain of the Puyallup River to the surface of the great Puget Lowland drift plain (veneered by glacial sediments) and crosses into the White River basin. As the highway approaches Buckley and Enumclaw it (almost imperceptibly) begins to traverse the deposits of the enormous Osceola Mudflow from Mount Rainier, which spilled out onto the drift plain about 5600 years ago. Near the Cascade Mountain Front), the road ascends a series of terraces and enters the broad glaciated valley of the White River, floored by a series of postglacial Mount Rainier mudflow deposits.

45.4 Optional field stop at Mud Mountain Dam. At the junction of SR 10 and the Mud Mountain Dam access road, drive 2.4 mi on the access road and then a short distance left to the dam viewpoint. Take the trail down to the viewpoint (20 min round trip).

Tom Sisson of the USGS has recently discovered that Three Sisters Ridge, the cone-shaped mountain to the southeast of this area (radio tower), was a Pleistocene volcanic vent. Sisson dated basaltic lava there at about 359 ka (Tom Sisson, written comm., 1998).

Here and there along the edges of the valley, 20-30 ft mounds of rock debris, mostly made up of Mount Rainier volcanic rocks are testimony to the passage of one of the worlds largest volcanic mudflows (Fig. 13). At Federation Forest State Park the road sits on top of series of terraces composed of lahars from Mount Rainier. Some of these lahars, called the Deadman Flat assemblage, were triggered by eruptions as recently as 1100 years ago and inundated areas downstream as far as the Port of Seattle (Pringle et al., 1997).

48.0 Roadcut on north side has hydrothermally altered Tertiary andesite estimated to be early Miocene by Hammond (1989). The rock is rich in alunite. A nearby caprock serves as a silica resource for the Superior quarry, one of Washington’s three silica mines.

FIGURE 13. Photo showing mounds in the Osceolo Mudflow deposit (about 5000 yr B.P.) located approx. 50 km from Mount Rainier.

50.9 Clearcut on north side of highway is on a large Quaternary landslide covering about 1 km^2 of hillside.

54.0 The road curves to the right. A quick view of the White River, adjacent to the highway, shows the high turbidity that results from glacial rock flour and other suspended sediments. The road passes over Twin Creeks. After about 0.8 mi, turn left on a spur road.

54.8 Optional Stop. Lahars in the Twin Creeks area. Take another sharp left just after turning onto the spur road and go about a mile to Twin Creeks. Lahars of the Deadman Flat assemblage and the Osceola Mudflow are exposed in the Twin Creeks area. Here, the highest exposure of the Osceola is at least 75 m above the White River and contains a large, cobble-bearing megaclast.

56.8 Federation State Forest. The road here is on a terrace underlain by lahars of the Deadman Flat assemblage, noncohesive lahars from Mount Rainier, the largest of which has been dated at 1120 ± 80 yr B.P. (Scott et al., 1995). The largest lahar in this assemblage was at least 18 m deep at this location.

At the Federation Forest State Park campground south of the highway, a water supply well penetrated the Osceola Mudflow at a depth of 61 m; the top of the Osceola is 11 m above the White River (Crandell, 1971).

58.2 Town of Greenwater. Lahars have left abundant deposits in this area, perhaps because the valley is fairly constricted downstream of here. The West Fork White River joins the White River about 2 mi to the east. This river drains the north slope and heads at Winthrop Glacier. The West Fork valley was one of the pathways of the Osceola Mudflow.

61.7 Optional Stop. Forest Road (FR) 74 turnoff to West Fork White River. About 1.7 mi up the West Fork, pre-Osceola lahar(s)? are visible as well as tephra layers P and Y from Mount St. Helens. At other sites along this road other lahar deposits are exposed above and below tephra layers W, Y, and C.

66.1 Entrance to Mount Baker/Snoqualmie National Forest.

66.5 View of the northeast slope of Mount Rainier through the valley of Huckleberry Creek.

67.7 FR 73 turnoff to the southwest up Huckleberry Creek. Follow the gravel road across a bridge for 0.7 mi to the Y, bear left and continue for another 0.4 mi to a small quarry.

68.8 STOP. Gravel pit exposure of Osceola Mudflow and nearby hummocks overlying Evans Creek drift (Fig. 14). In the gravel pit a 3-4-m-thick layer of the Osceola Mudflow overlies a boulder/cobble unit of Evans Creek Drift (about 22–11 ka). Rounded Mount Rainier layer C tephra overlies the Osceola, mixed with soil. The Osceola has a high clay content (2-15%, mean of 7%) (Scott et al., 1995). Note the oxidized zone in about the upper 3 m of this outcrop. About half the rocks in this Osceola outcrop are from Mount Rainier; others are exotic rocks picked up by the lahar as it flowed. Wood from the basal 50 cm of the Osceola Mudflow here was dated at 4455 ± 310 yr B.P.

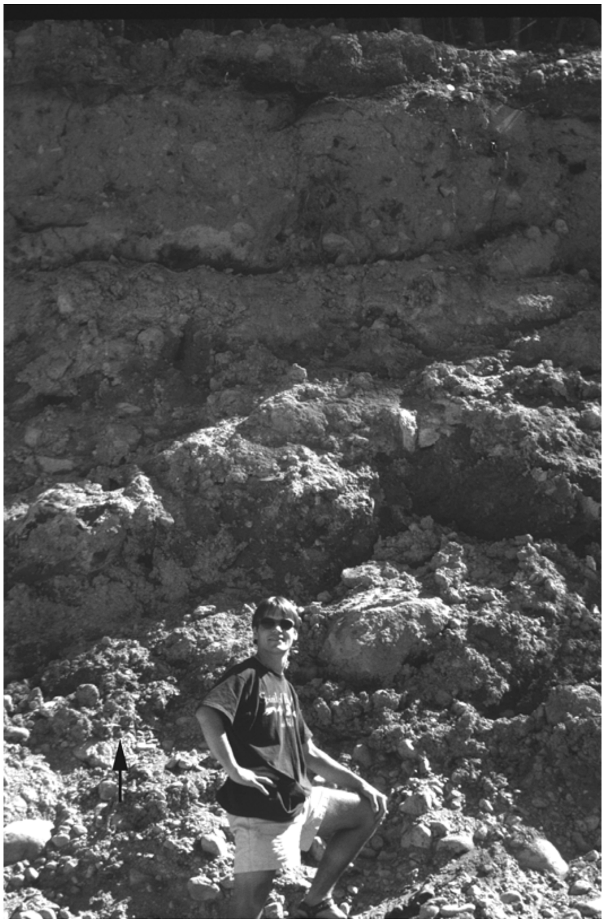

FIGURE 14. Photo showing the Osceola Mudflow deposit overlying Evans Creek (Alpine) glacial outwash from Mount Rainier. Arrow to the left of Paul Cordy shows bottom of the Osceola deposit.

Approximately 200 m west of the gravel pit several hummocks are visible. These features were once considered to be a distinct depositional unit from a separate event, the Greenwater lahar of Crandell (1971). However, Vallance found only one lahar unit exposed in each of four test pits, two pits adjacent to hummocks and two between the hummocks and the quarry outcrop of Osceola (Scott et al., 1995). The hummocks, mainly monolithologic rock debris from Mount Rainier, are apparently from a marginal facies of the Osceola Mudflow that was grounded or stranded in backwater areas.

The entrance road is on a low terrace composed of at least one, and locally two or more, noncohesive lahars from Mount Rainier. The Deadman Flat lahars contain abundant vitreous, commonly scoriaceous, black Mount Rainier Andesite, similar in appearance to the rocks of Columbia Crest cone. Some rocks in the lahar are prismatically jointed, angular blocks that indicate the lahar was generated by pyroclastic/snow-ice interaction. The principal unit of the Deadman Flat lahar assemblage filled the White River valley to depths of 20 m in this area and flowed as far as Auburn in the Duwamish valley. Runouts from the Deadman Flat lahars compose terraces in the lower White River mapped by Crandell (1963; his Plate 1) as Terrace Alluvium (unit Qatw). The tops of the terraces are as much as 18 m above the White River.

Return to SR 410 and turn right. Proceed up the White River debris fan.

71.0 Dalles Campground.

71.9 Light-colored bedrock outcrops east of the road are Stevens Ridge Formation volcaniclastics (Fiske et al. 1963). This formation ranges from late Oligocene to early Miocene. Source of this unit is unknown.

76.4 Dark-colored bedrock outcrops east of the road are Ohanapecosh Formation volcaniclastics of Eocene-Oligocene age.

77.0 Silver Springs. A water-supply well for a USFS ranger station penetrated the Osceola Mudflow at a depth of about 15 m and was still in it when drilling stopped at 61 m. Nearby the mudflow also veneers the valley sides 38 m above the river (Crandell, 1971).

78.0 Mount Rainier National Park boundary.

79.9 Vertical contact between Ohanapecosh Formation and Sunrise Point pluton. This is the northern boundary of the Sunrise Point pluton. Eocene Ohanapecosh Formation lavas and breccias make up the country rocks. The contact slices across contours on either side of the White River and is only mildly altered, unlike the hornfelsed Ohanapecosh rock farther upstream. The Sunrise Point pluton is a quartz monzonite at this location and will be described at the type locality, MP 4.0 of the Optional trip to Sunrise.

The Sunrise Road — SR 410 to Sunrise

82.5 Turnoff, Yakima Park Road to Sunrise veers off to southeast. View is up the White River which heads at Emmons Glacier and drains the east side of the volcano. The White River was a major pathway for the Osceola Mudflow. Orange diamicts in roadcuts along the road are scattered remnants of the Osceola Mudflow.

85.1 Shaw Creek.

87.7 Junction of Yakima Park Road and White River Campground Road. Turn left into the campground and drive to the far west end. The clay-rich Osceola Mudflow overlies debris flow deposits at the road junction. Porter et al. (1965) estimated that the mudflow was at least 210 m thick here.

89.0 **OPTIONAL STOP. White River Campground**. Emmons Moraine Trail and views of Emmons Glacier, view of the caldera like form created by Osceola Mudflow, Columbia Crest cone, and 1963 debris avalanche. We hope for good visibility at this stop (4800 ft), but even a partial view can be spectacular.

The type locality for the quartz diorite of White River is found about 0.5 km up the road to the campground (Mattinson, 1977). At that spot, the rock is a mediumgrained, light-grey, equigranular assemblage of plagioclase, quartz and orthoclase with lesser biotite, hornblende, magnetite, sphene, apatite and chlorite. Two populations of zircons in that pluton yielded identical U-Pb ages of 14.1 Ma (Mattinson, 1977). Farther up the White River, the hornfels-grade contact between the White River pluton and the Ohanapecosh Formation is exposed. On the north side of the river, just down stream of the bridge, mafic synplutonic dykes are exposed in stream-polished outcrops of the White River pluton.

We will hike west on the Inter Fork Trail from the west end of the White River Campground about 1.6 km. taking the Emmons Moraine Trail to the left across Inter Fork of the White River and hike up to a vantage point on a moraine. Total elevation gain is about 700 ft (213 m).

Trip to Sunrise

This trip ascends the Yakima Park lava flow to the Sunrise area, where, on a fine day, there awaits spectacular vista of Mount Rainier (Fig. 15).

0.0 The Osceola Mudflow is locally visible as a <10 m veneer for about the next 1.0 mi with tephra layers Yn, C, and Wn visible on top of it in some outcrops. Spectacular columns of Mount Rainier Andesite, as well as till, a tephra of pre-Evans Creek age (>38 ka), and beds of fine-grained material (glacial-lake deposits) are visible between road miles 1.7 and 2.1. One mica-rich Mount Rainier tephra unit exposed here was sampled by Yukio Hayakawa. Analysis provided to him showed a possible correlation with the Washtucna tephra of eastern Washington (based mainly on refractive index); if so, this unit could be between about 13 000 and 45 000 years old (Berger and Busacca, 1991; McDonald and Busacca, 1992).

1.8 Pulloff to see tephra deposits underlying Evans Creek-age glacial deposits.

2.8 Yakima Park flow of the Mount Rainier Andesite. This flow is one of the longer intracanyon flows preceding the main cone-building stage of the volcano. (See Fiske et al., 1963). The flow apparently followed the course of the ancestral White River and chilled against the walls to form the picturesque columnar joints exposed in the road cut.

4.0 Sunrise Point switchback parking lot. This is the type area of the Sunrise Point quartz monzonite of Mattinson (1977). At most outcrops the rock is a light-grey to greenish-grey, medium- to fine-grained, equigranular quartz monzonite composed of plagioclase in a granophyric matrix of K-feldspar and quartz. Biotite, chlorite and hornblende are less common. Magnetite, ilmenite, titanite, and epidote are also present. The rock is commonly altered. U-Pb zircon data (Mattinson, 1977) suggest an age of 24 Ma, considerably older than the White River pluton. From this last switchback, the road to Sunrise cuts through granodiorite of the Tatoosh pluton.

8.7 Upper contact between Ohanapecosh Formation and Sunrise Point pluton. A complex upper and lateral boundary with the Ohanapecosh Formation is exposed here.

9.3 Roadcuts to north expose Mazama ash (layer O) overlain by blocky rubble of layer S and pumiceous layer C. This is the locality for Crandell's figure in Bulletin 1238 and is a good place for a short stop on the return from Sunrise (mi 10.9).

10.1 Parking area. Sunrise.

From Sunrise one can see the amphitheater-shaped caldera created by the Osceola Mudflow (Fig. 15). Remnants of the caldera rim are seen at Point Success, Liberty Cap, the uppermost exposures of Willis Wall, and other headwalls. The upper tips of dark ribs (probable flow levees) that protrude through Emmons Glacier may indicate the floor of the caldera, which is open to the northeast. Alternatively, these flows may be of post-Osceola age and may have been truncated by an explosion during eruption of the C tephra.

The volume of the Osceola Mudflow, at least 4 km^3 (Dragovich et al., 1994), is enough to fill much of the caldera embayment if the eruptive products of the last 2400 years are removed. The Osceola entered both the White River and the West Fork White River, which drains the sector of the volcano north of Sunrise including Winthrop Glacier. Mount

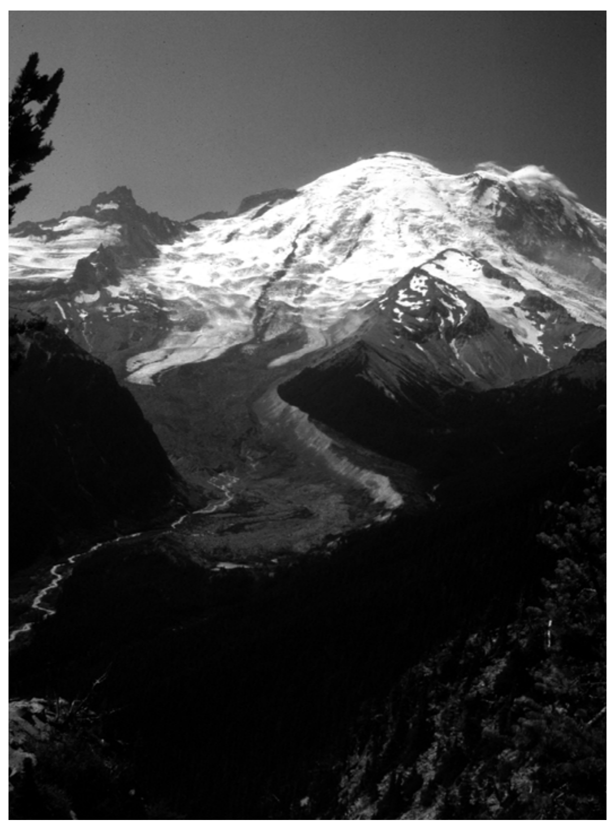

FIGURE 15. Photo of east face of Mount Rainier from Sunrise.

Rainier tephra units B and H were erupted shortly after the Osceola Mudflow; an apparent period of extended repose of more than 2000 years followed. Presumably, a caldera whose floor comprised the exposed internal workings of a hydrothermal system existed at the top of Mount Rainier during this period. Surficial acid alteration would likely have produced a blanket of clay-rich material across the surface of the caldera floor during the repose period.

Renewed eruptive activity about 2400 years ago, as represented by a block-and-ash flow on the southwest flank, tephra layer C, and numerous noncohesive lahars rich in angular, vitreous andesite (similar to the rocks composing the Columbia Crest cone), mark the beginning of the most recent period of cone construction. A younger episode, perhaps lasting from about 1400 to 1000 years ago, probably produced some of the Deadman Flat deposits. During this period, and including later activity, the caldera has been filled to overflowing by Columbia Crest cone, a young summit cone made up primarily of lava flows and flow rubble. As a consequence of the likely extent of hydrothermal alteration, the Columbia Crest cone sits in an amphitheater analogous to a greased bowl. Moreover, the bowl is tilted to the north, and its contents slop over the edge.

The 1963 debris avalanche deposits are plainly visible on the surface of the Emmons Glacier, from which the White River can be seen emerging. The deposit, which is made up of at least seven distinct avalanches, extended about another 1.6 km downstream to within 0.8 km of the White River Campground and had a volume of about 11 x 106 m^3 (Crandell and Fahnestock, 1965). Fortunately the avalanches occurred in December when the area was deserted. Estimates of flow runup onto the back of a terminal moraine indicated a distal velocity of 35-40 m/s (79-90 mph). High velocities, almost certainly in excess of 30 m/s (68 mph), increase the risk with this type of event.

The avalanches originated from the side of Little Tahoma Peak, possibly triggered by a steam explosion. The flow passed over an old gage house, leaving it relatively undamaged, evidence that the flow possibly was riding on a cushion of trapped air.

In July 1974 and again on August 16, 1989, similar but smaller avalanches, fell from Russell Cliff and traveled 2 to 4 km down the Winthrop Glacier. Although the 1989 avalanche was only about 10 percent of the size of the Little Tahoma Peak avalanches, seismic signals generated by it were recorded as far away as 200 km (Norris, 1994). The size and nature of the seismic signal of the Russell Cliff avalanche led curious seismologists to recheck the records from December 1963. They discovered a large signal on December 6 that is tentatively thought to correlate with the avalanches from Little Tahoma Peak (which was previously thought to have occurred on December 13 or 14, 1963) (Norris, 1994).

10.1 This optional hike goes north from the parking area and up about 400 ft (120 m) onto Sourdough Ridge to a saddle. There we will view an outcrop of a biotite-phyric pumice deposit that may record the largest known explosive eruption of Mount Rainier (Fig. 16). The 2-m thickness of this unit 12 km northeast of the present Mount Rainier summit is greater than that of tephra layer Yn (3600 yr B.P.) at an equivalent distance from Mount St. Helens (Mullineaux, 1986, 1996). The volume (dense rock equivalent) of layer Yn has been estimated at 4 km^3 (Carey et al., 1989). The tephra clasts are crumbly and many represent fragments of much larger clasts. The origin of a fragmental deposit overlying the tephra is unclear.

FIGURE 16. Photo of U-tephra layer on Sourdough Ridge. This tephra, is bracketed in age between 30-140 ka, may represent the largest know explosive eruption of Mount Rainier volcano.

Is this explosion ejecta or possibly part of a glacial moraine? Kirn's (1995) study of the U tephra suggests that the magma erupted was much more silica rich (69.4 wt % SiO_2) and cooler than the more recently erupted dacites, and had to come from a storage region at greater depth.

The crest of Sunrise Ridge is composed of lavas and breccias of the Mount Fremont dome complex. The Mount Fremont aphanite (Fiske et al., 1963) is andesite to dacite in composition with plagioclase the only abundant phenocryst. Rare augite and magnetite/ilmenite are also found. This unit has not been dated; however, it is probably slightly older than the 25.1 Ma (Mattinson, 1977) tuff of the Palisades, exposed about 3 km to the north. Mapping of crumble breccia, vent-filling tuff breccia, aligned vesicles and flow foliation (Murphy and Marsh, 1993) reveals at least two vents in this vicinity, subparallel and northwest-southeast trending. A good cross-section of the dome complex can be seen during the short (4 km) hike to the Mount Fremont fire lookout. Fine-grained, laminated, well-indurated rocks are found on the tops of McNeeley Peak and Dege Peak, probably either Fifes Peak Formation-equivalent (Fiske et al., 1963) or associated with late-stage dome explosion or epiclastic degradation (Murphy and Marsh, 1993).

The optional 5-km loop hike to Frozen Lake transects the excellently exposed upper contact of the Sunrise Point pluton and the overlying dome complex. Look for the granitic rocks along the creek draining Frozen Lake, but try to stay on the trail elsewhere. The meadow biota are highly sensitive to foot traffic.

The Emmons Vista trail (0.3 mi round trip) leads to several scenic overlooks.

10.9 "Sourdough rubble" (tephra layer S). Across from a turnout on the left (south) side of the road is an exposure of tephra layer S. This layer is visible here as a 15-cm-thick train of sand and angular Mount Rainier rocks about 1 m below the top surface. Layer O is exposed immediately underneath layer S. The layer is found on Goat Island Mountain (there consisting of much larger blocks) and northward to Huckleberry Park. This layer apparently was deposited by a laterally directed phreatic explosion. Rocks greater than 50 cm in diameter can be found about 10 km from the summit. These are not similar to the Tertiary rocks composing the ridge to the north. This deposit was formerly known as the Sourdough Rubble (Stop 4-2 in Porter et al., 1965). Exposures of fresh Mount Rainier rocks exposed in gullies along the Silver Forest Trail could also be part of layer S.

End of trip to Sunrise.

Return from White River Campground to SR 410 on Yakima Park Road and reset mileage to zero there.

0.0 Junction of SR 410. Turn right and continue to Cayuse Pass.

2.0 First large landslide of Tertiary rock into Klickitat Creek.

2.8 Second large landslide into Klickitat Creek. The parkway crosses it by curving around to the right along contour. A landslide mass in the Ohanapecosh Formation has moved westward into Klickitat Creek. Ghost Lake may sit on the landslide because no tree snags are visible in the lake, as could be expected if the lake were upstream of an impoundment. Measurement of the thallus diameters on two lichens (*Rhizocarpon geographicum*) on rocks adjacent to the lake were in excess of 85 mm. Using a calibration curve established by Porter (1981), these measurements suggest an age of at least 180 yr for the lichens—and probably more, considering climatic factors.

3.3 Cayuse Pass, turn right onto SR 123 and continue south toward the Ohanapecosh Entrance of Mount Rainier National Park at Stevens Canyon Road.

6.1 Tunnel.

14.2 Turn right at intersection of Stevens Canyon Road with SR 123 and pass through the rugged valley of the Ohanapecosh River, the other main headwater tributary of the Cowlitz River.

14.4 Grove of the Patriarchs. Only 0.2 mi from the intersection of SR 123 and Stevens Canyon Road is the Grove of the Patriarchs trailhead. A short (50 min round trip) walk leads to an old-growth forest of huge Douglas firs and western red cedars that probably are at least 1000 yr old. Their great age and low position on an island in the middle of the Ohanapecosh River indicate that no lahars of any magnitude have originated in this drainage in at least 1000 years.

En route to Paradise, outcrops of the Tertiary Ohanapecosh Formation are exposed on backbone ridge.

17.5 For the next 2 mi the road climbs up through the thickest section of the Ohanapecosh Formation (Fiske et al. 1963). Near the top of the ridge at mi 113.3, scattered pods of green, red, and purple masses are fragments of saprolites that were, along with rocks of the underlying Ohanapecosh formation, ripped up and incorporated into basal ash flows of the overlying Stevens Ridge sediments. "Fragments of bedrock, saprolite, streamrounded pebbles, and bits of macerated wood were swirled upward as much as 50 ft into the base of the ash flow" (Fiske et al., 1963).

20.0 Turnout on the south side of the road provides a magnificent view of the southwest slope of Mount Rainier with Little Tahoma Peak on the right skyline, Success Cleaver on the left skyline, and Cowlitz Glacier tumbling toward the viewer.

As the road descends from here to the Cowlitz River, cuts expose light-colored Stevens Ridge pyroclastic flows for about the first 2 mi followed by underlying Ohanapecosh breccias.

24.2 Nickel Creek.

24.5 Box Canyon overlook. Spectacular postglacial incision, glacial striations. No lahars comparable in size to the largest debris flows in most other drainages have originated in the Cowlitz River watershed. However, the broad floodplain downstream (known as the "Big Bottom") is underlain by distal phases of many lahars that occurred in the last 1000 years. Several major floods inundated the 1.5- to 3-km-wide floodplain to depths of at least 2 m around the turn of the century.

At Box Canyon the Cowlitz River has cut deeply into the volcanic bedrock. The footbridge 0.1 mi upstream is the best vantage point. Greenish cut stone used to line the bridge, walkway, and parking area are blocks of mudflow breccias of the Oligocene Ohanapecosh Formation. The greenish color is due to zeolite-facies metamorphism.

This site is an example of why stratigraphic studies of a volcano must include areas beyond the base of the volcano in order to provide a complete picture of lahar magnitude and frequency. Many lahars have passed this point, yet none is preserved here. A complete flow record is revealed only in the depositional regimes of the downstream valleys. Deposits on the volcano itself may be thin and quickly eroded or may be covered by the deposits of later eruptions. Glacial erosion and deposition are added complications. At Mount St. Helens a series of surges that were derived from breakouts of avalanche-dammed lakes did not incorporate enough sediment to form debris flows until they reached a point 19 km from the base of the volcano. About 50 km from the volcano, one of these debris flows had a peak discharge of 200,000-300,000 m^3/s, comparable to the Amazon River at flood stage, (Scott, 1988).

24.7 A "textbook"-quality sill of Tatoosh dacite porphyry (visible behind the vehicle above the lee side of the first tunnel heading west) intrudes darker intrusive rocks of the Fifes Peak Formation. Visible for the next 2 mi is Miocene Stevens Ridge Formation (welded tuff) at its type locality.

Stop to see Stevens Canyon Lava flow and Tertiary Stevens Ridge Formation welded tuff. We will pull off in this area to observe the Stevens Ridge welded tuff, on the north side of the valley, and the Stevens Canyon lava flows, which were interpreted by Fiske et al. (1963) to be evidence for inverted topography (the two benches visible to the south were interpreted to be two separate flows). These flows have been dated about 99 ka by Sisson and Lanphere (1997). Curved and chaotic fan-shaped lava columns suggest chilling against ice. Dave Lescinsky and Tom Sisson (1997), however, show that many (most? all?) of the ridge capping lavas originally proposed as reversed topography (Fiske et al. 1963), in fact formed through confinement of lava to ridge sides and crests by thick valley ice during the Pleistocene (Fig. 17). Sisson explains (written comm., 1998): "in Stevens Canyon, look across the valley and notice the benches in the lava. One lies just upstream of the valley of Unicorn Creek and one lies just upstream of the outlet of Maple Creek. Chemical compositions and four radiometric ages confirm that the Mazama Ridge (see below and at mi 32.7), Bench, and Stevens Canyon lavas are all the same flow and do not result from eruptions spaced widely in time and separated by long periods of erosion (previous interpretation). Apparently, lava flowed down Mazama Ridge, bounded on the sides by ice in the valleys of Paradise Creek and Stevens Canyon. When the lava reached the end of Mazama Ridge it was diverted to the east by running into the Tatoosh Range. The lava proceeded along the margin of the Stevens Canyon glacier (paleo-Paradise glacier) until it ran into a tributary ice stream in the valley of Unicorn creek. The lava temporarily stopped and thickened until it melted through the Unicorn glacier, and then it continued down the margin of the main Stevens Canyon glacier until it ran into the tributary glacier in the valley of Maple creek. The lava was dammed again and thickened

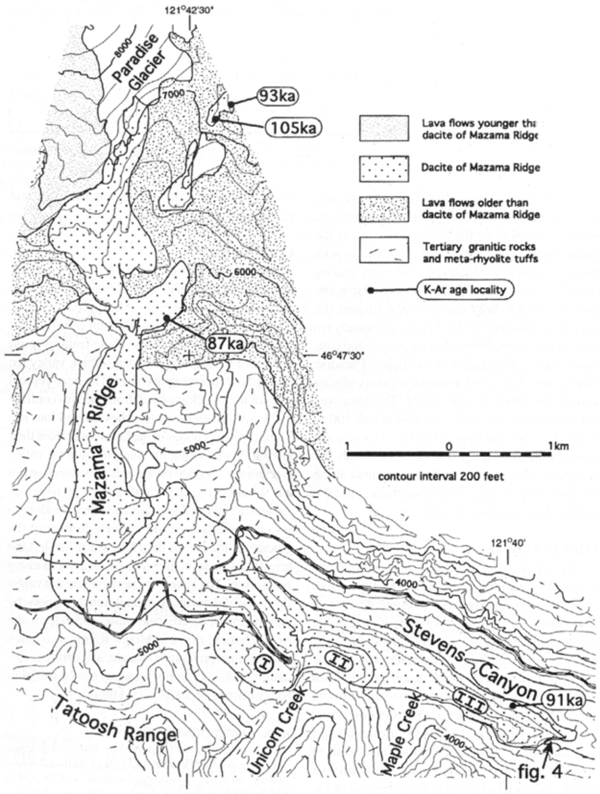

FIGURE 17. Diagram from Lescinsky and Sisson (1997) showing spatial relationship of Mazama Ridge and Stevens Canyon lava flows. Dates shown by Sisson and Lanphere (1997). Lescinsky and Sisson explain the emplacement mechanism for this and other ridge-forming flows as being controlled by bounding ice (see text).

until it melted through that ice and continued down a meltwater channel that lay on the margin of the main Stevens Canyon glacier until the eruption ended."

26.1 Slightly beyond the next (second) tunnel the Stevens Canyon Road passes the contact between the bedded Stevens Ridge pyroclastic flows and the Tatoosh granodiorite.

28.2 Stevens Creek. Mazama Ridge to the north, a lava flow, is a major drainage divide. Stevens Creek, which drains the last vestiges of Paradise Glacier, flows into the Pacific Ocean by way of the Cowlitz and Columbia Rivers. The Paradise River, on the other side of Mazama Ridge, drains to Puget Sound via the Nisqually River. Ironically, because of glacial retreat, the Paradise River no longer drains the Paradise Glacier.

31.3 Reflection Lakes. The lakes occupy shallow depressions in the Paradise Lahar. In order to reach the Reflection Lakes area, the lahar had to spill through a saddle in Mazama Ridge and down Stevens Canyon into the Cowlitz watershed. Continue west on Stevens Pass Road toward Paradise Road.

32.7 Inspiration Point. As noted above by Tom Sisson, the Mazama Ridge lava flow visible here has the same chemistry as the Stevens Canyon flows. Sisson also has noted that a pumice deposit seen by Crandell (1963) that underlies this lava flow is correlative with the biotite-phyric pumice on Sunrise Ridge (layer U of Venezky and Rutherford, 1993). This deposit is visible north of the viewpoint in the cliff face. The valley of Paradise Creek is located to the southwest, bounded on its west and north side by the Mazama Ridge Flow. Look at the view to the southwest along the Paradise Valley to gain some perspective on the dynamics and stage height of the Paradise lahar, whose deposits we will see tomorrow (Fig. 18).

33.0 Stevens Pass and Paradise Road intersection. Turn right and drive toward Paradise passing orange and brown deposits of the Paradise debris flow and tephra deposits.

35.0 End today's journey at Paradise.

September 29, 1998

On this day we will have optional free time for those who want to explore on their own. However, if enough people are interested, we might offer an optional visit to Ricksecker Point to see Paradise Lahar and bounding tephra deposits as well as evidence for interaction of Ricksecker Point lava flow and ice, to the Tahoma Creek area to see the deposits of recent glacier outburst floods (jokuhlhaups), and(or) down to Kautz Creek and several other locations and return to the Paradise Lodge.

Hiking in the Paradise area. Boulders of the Paradise lahar deposit lie on the ground surface here. The lahar deposit and various tephra layers are visible in exposures at the parking area and along the trails (Fig. 19). We will hike to Glacier Vista (6 km round trip; elev. gain about 600 ft+) to observe the Nisqually Glacier, neoglacial moraines, and Mount Rainier lava flows, breccias, and block and ash deposits (Fig. 20).

Details of the geology can be found in Pringle et al. (1994a,b).

Optional Day Excursion to Ricksecker Point, Kautz Creek, and Tahoma Creek. Rezero odometer, leave Paradise, and head toward Longmire. For an optional trip, go along the exit road that follows the Paradise Valley.

0.0 leave north end of Paradise parking lot near lodge and drive down through the beautiful valley of the Paradise River. In the winter this area is a favorite spot for Alpine skiing.

0.4 Edith Creek and Myrtle Falls in a narrow chasm.

0.6 Paradise River and "Fourth Crossing Trail". Tatoosh rocks with veining on the left and Paradise Lahar on top of it.

1.2 Glacially smoothed Tatoosh rocks visible just before curve to left. A glacial till outcrops upstream. The Paradise Lahar deposit near this location is draped by about 9 in (23 cm) of Y tephra from Mount St. Helens.

1.3 Multicolored layers of ash are exposed to the east of the road on top of an unsorted deposit, probably the Paradise Lahar.

1.9 A pulloff for the Lakes Trail is just before a sharp turn to the right. The 4.8 mi (7.5 km) trail connects with several other trails including the Skyline Trail. This is a good location to stop and park if you want to take a closer look at the ash layers.

2.3 Stevens Canyon Road.

Retrace the Westside Road back to Paradise.

End of this section of trip.

September 30, 1998

Today we leave Mount Rainier National Park via the Nisqually entrance. We will travel west along the edge of the Nisqually valley and, at Elbe, will cut south across the Nisqually River, up over a divide, and into the Cowlitz River basin. At Morton, we will switch to the roadguide published in the Mount St. Helens guidebook (see milepoint 14.1 below). After our visit to the Johnston Ridge Observatory at Mount St. Helens, we journey north to Seattle.

0.0 Mount Rainier National Park, Nisqually entrance.

2.2 Kernahan Road. This road becomes FS 52 and leads to Packwood and interesting hiking trails such as the High Rock Lookout trail (excellent view of Mount Rainier and Kautz Creek area from a hogback Ridge to the south.

14.1 Turn left from SR 706 onto SR 7 and continue 17 mi south to Morton and then head west on US 12. At Morton field trip guide continues (in reverse) in Leg E of Pringle (1993) at milepoint 31.9 (his p.87). After going west on SR 12, we will go south and access Mount St. Helens National Monument via SR 504, Leg A of Pringle (1993). That leg begins on his p.41.

End of of trip, Seattle, Washington.

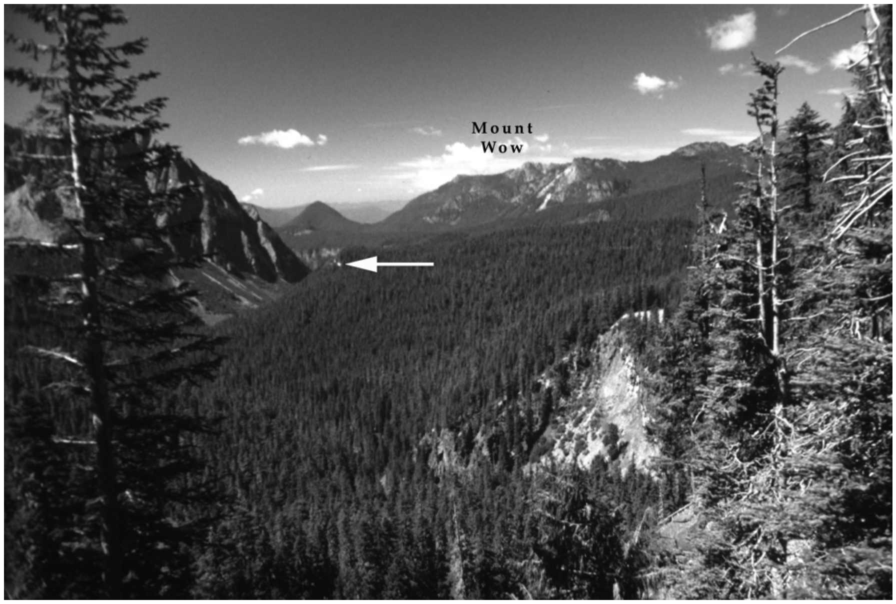

FIGURE 18. View to the southwest of Paradise valley and the Ricksecker Point lava flow which bounds it on the west and west. Lescinsky and Sisson (1997) interpret the lava flow as another ridge-forming ice-bounded flow, such as the one noted in Figure 17. Arrow shows the maximum inundation height of the 5000 yr B.P. Paradise lahar (800 ft or 244 m above the valley bottom) as indicated by deposits exposed at Ricksecker Point (Crandell, 1971; Scott et al., 1995).

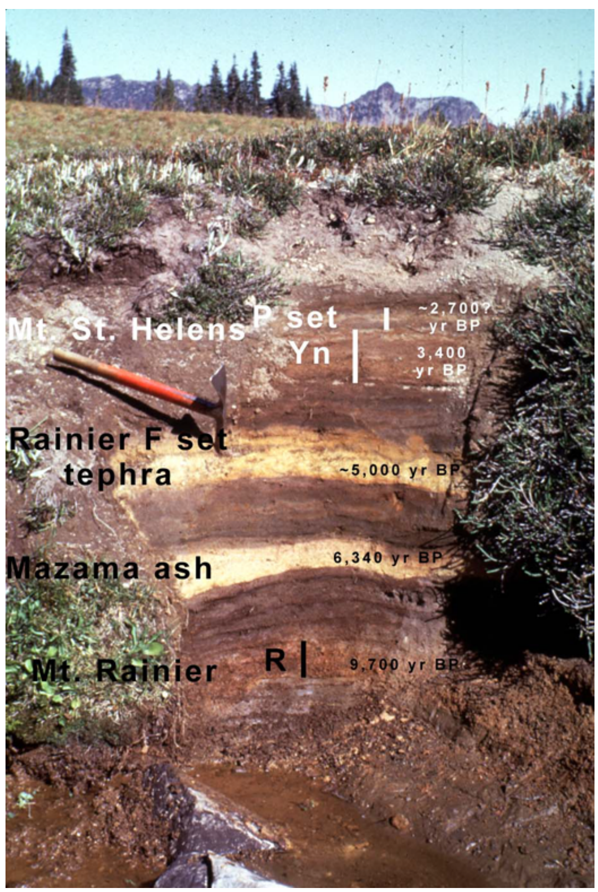

FIGURE 19. Tephra layers from Mount Rainier exposed at McNeely meadow area; photo by Don Mullineaux (Fig. 7 in Mullineaux (1974)). This site is about 0.7 km north of the ranger station at Sunrise.

FIGURE 20. View of Mount Rainier and upper Rampart Ridge from Glacier Vista. A detailed stratigraphic section of part of Rampart Ridge by Tom Sisson is found on p. 2G-14 of the field guide by Pringle et al. (1994a,b). Sisson and Lanphere (1997) have dated the welded block and ash flow at about 300 ka.

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